LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-CONF-458495

Monte Carlo Simulation of the Prompt Dose Environment in the National Ignition Facility during Low Yield D-T Shots

H. Y. Khater, S. J. Brereton

October 6, 2010

The Joint International Conference of the 7th Supercomputing in Nuclear Application and the 3rd Monte Carlo (SNA + MC2010)
Tokyo, Japan
October 17, 2010 through October 21, 2010

Disclaimer

National Ignition Facility

Monte Carlo Simulation of the Prompt Dose Environment in the National Ignition Facility during Low Yield D-T Shots

Joint International Conference on Supercomputing in Nuclear Application and Monte Carlo 2010

Tokyo, Japan
October 17-21, 2010

Hesham Khater and Sandra Brereton

Lawrence Livermore National Laboratory

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

Outline

I. Introduction to the NIF

II. The NIF facility modeling

III. Prompt dose results for different shot categories

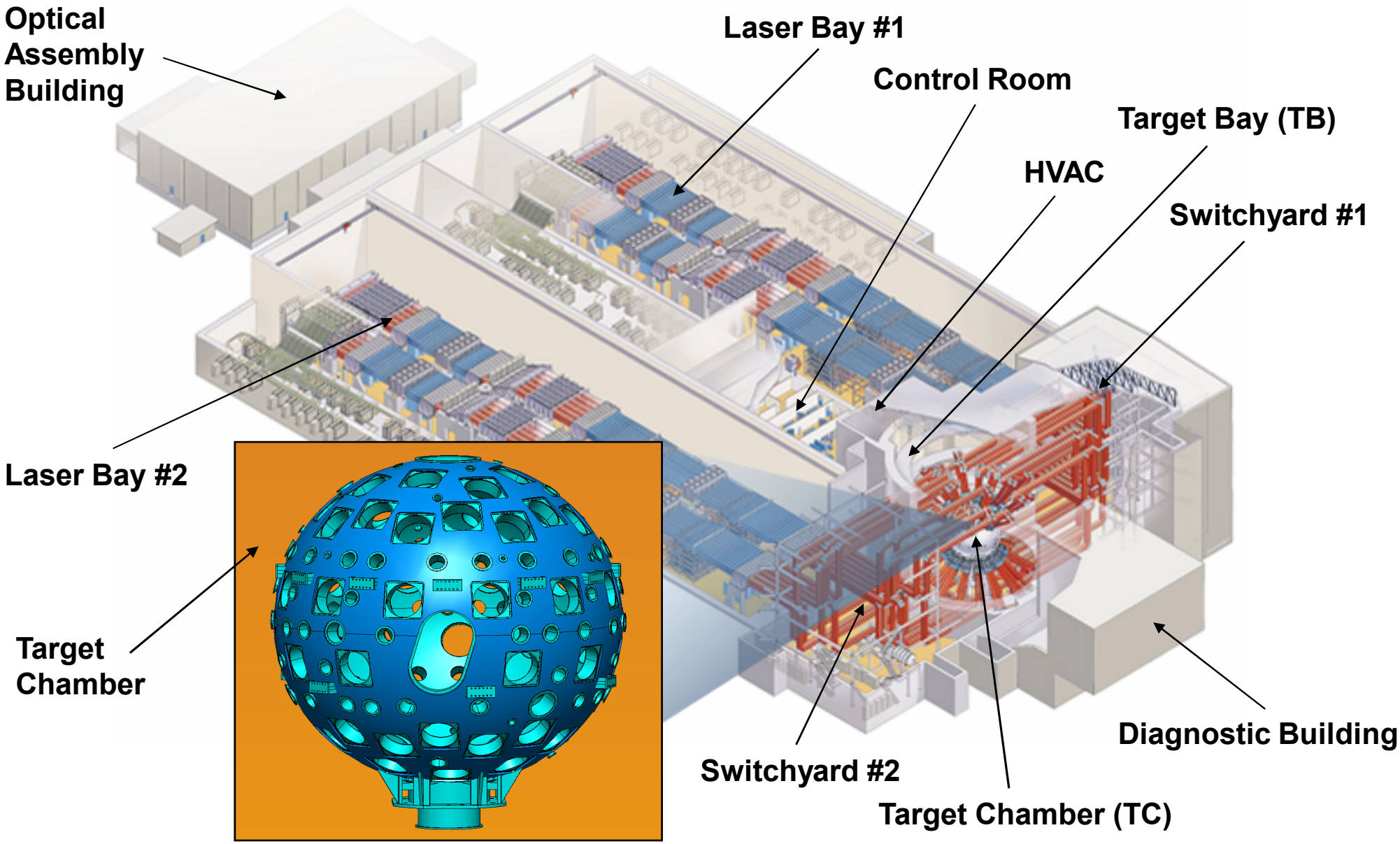
V. Summary

Introduction

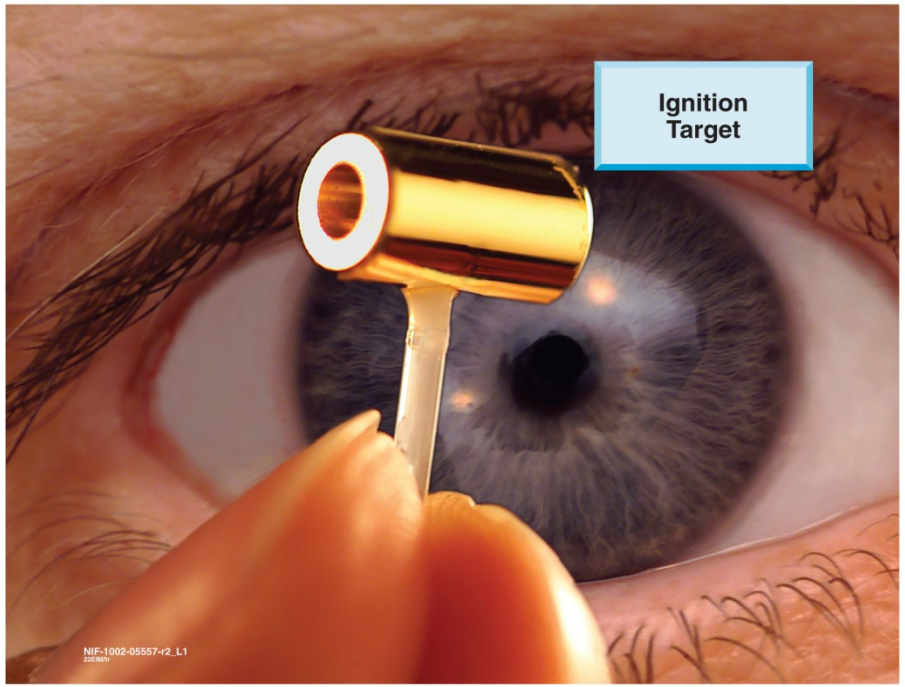
- Detailed 3-D modeling of the NIF facility is developed to accurately simulate the radiation environment within the NIF
- Prompt dose values are calculated for different phases of NIF operation
- Results of the analysis were used to determine the final thicknesses of the Target Bay (TB) and secondary doors as well as the required shield thicknesses for all unused penetrations
- Integrated dose values at different locations within the facility are used to formulate the personnel access requirements within different parts of the facility and for different shot categories


192 Pulsed Laser Beams
Energy 1.8 MJ 3ω
Power 500 TW

NIF Layout


Optical Assembly Building
Laser Bay #1
Control Room
Target Bay (TB)
HVAC
Switchyard #1
Laser Bay #2
Target Chamber
Switchyard #2
Target Chamber (TC)
Diagnostic Building

Ignition point design target



Laser Beams in 2 rings (24 quads)

Capsule (CH, Be or Diamond)

Solid DT fuel layer

9.2 mm

Hohlraum Wall (Au)

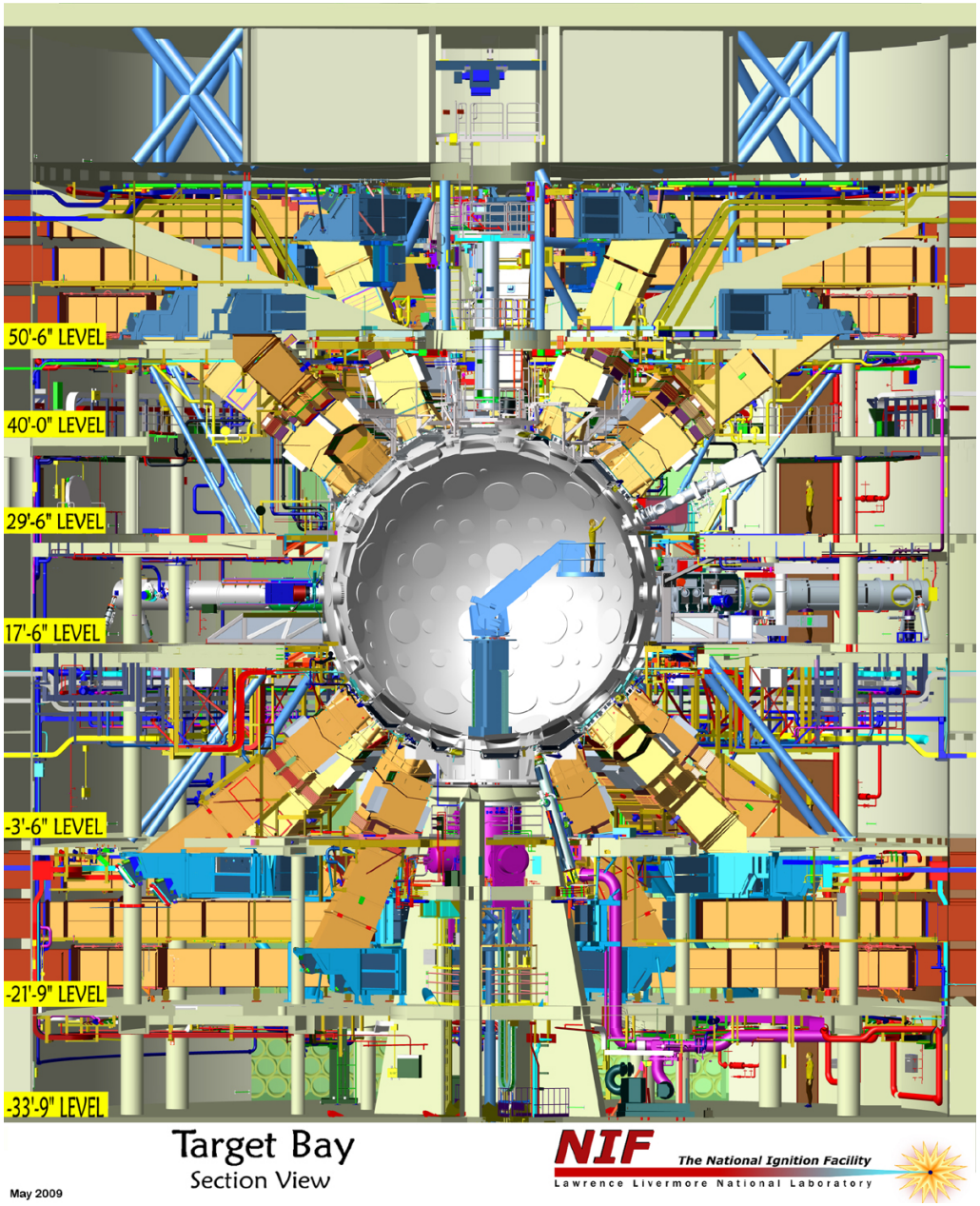
Hohlraum Fill – He gas (1.3 mg/cm^3)

Laser Entrance Hole (LEH)

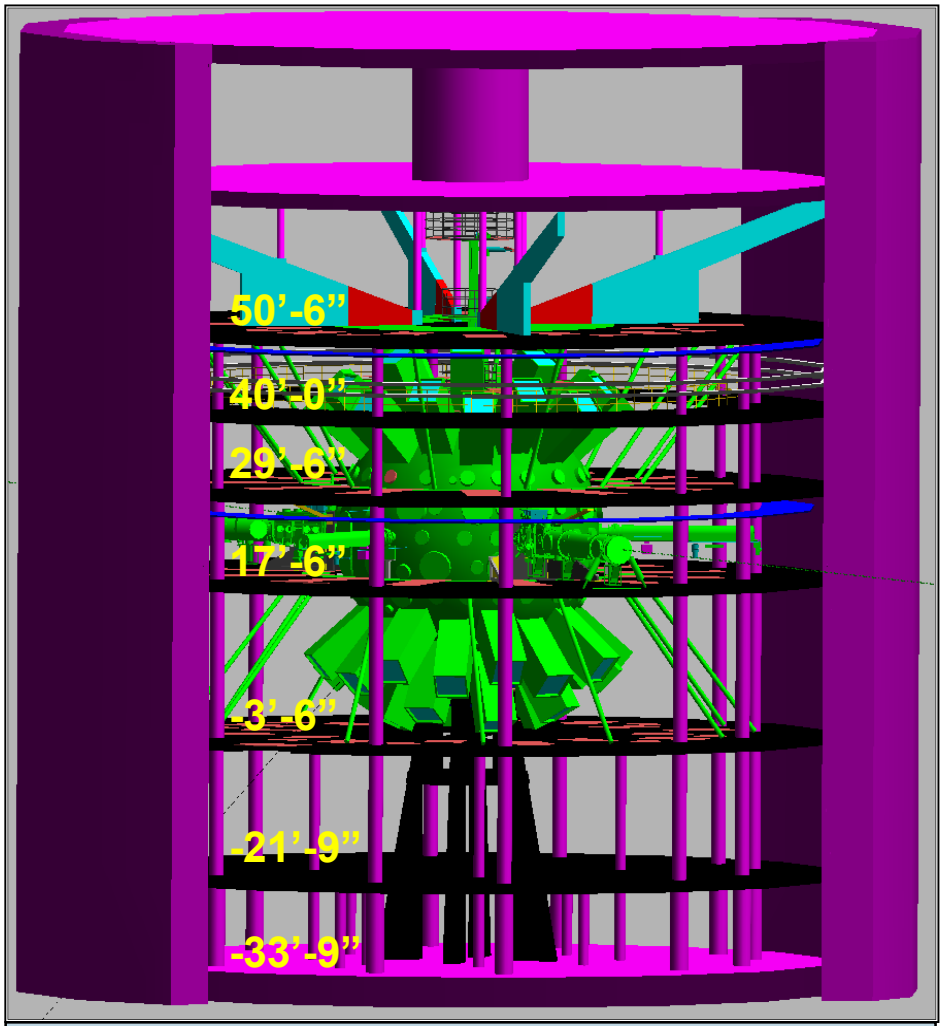
Features of the current NIF facility model

- Based on the facility as-built drawings
- 10-cm-thick Al Target Chamber (TC) wall surrounded by 40-cm of borated concrete
- 6'-thick concrete Target Bay (TB) wall
- 3'-3"-thick concrete Switchyard walls
- All Target Chamber, Target Bay and Switchyard wall penetrations are modeled
- Diagnostics and Direct Drive ports are only covered with ~ 2" aluminum
- Final Optics Assemblies (FOAs) are modeled

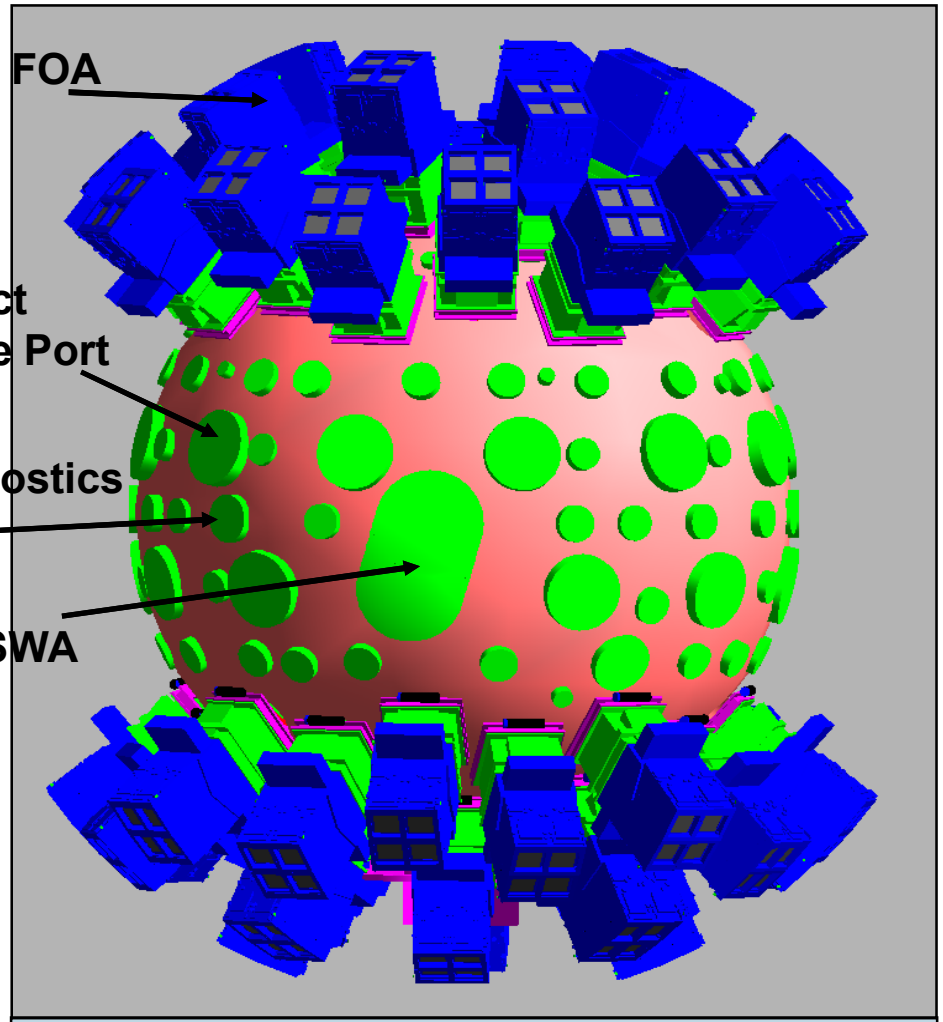
Sectional view of the Target Bay



MCNP models



Target Bay

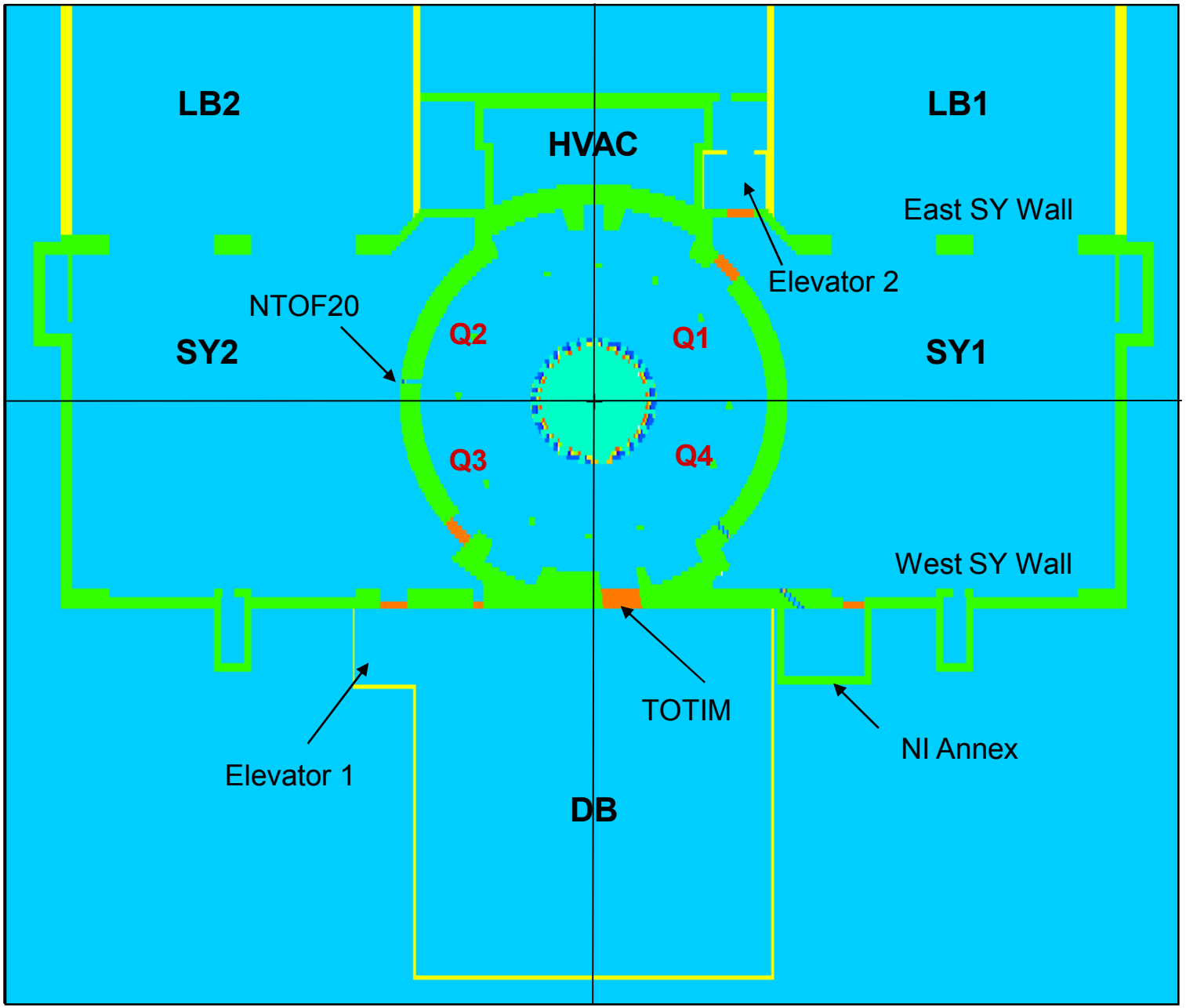


Target Chamber

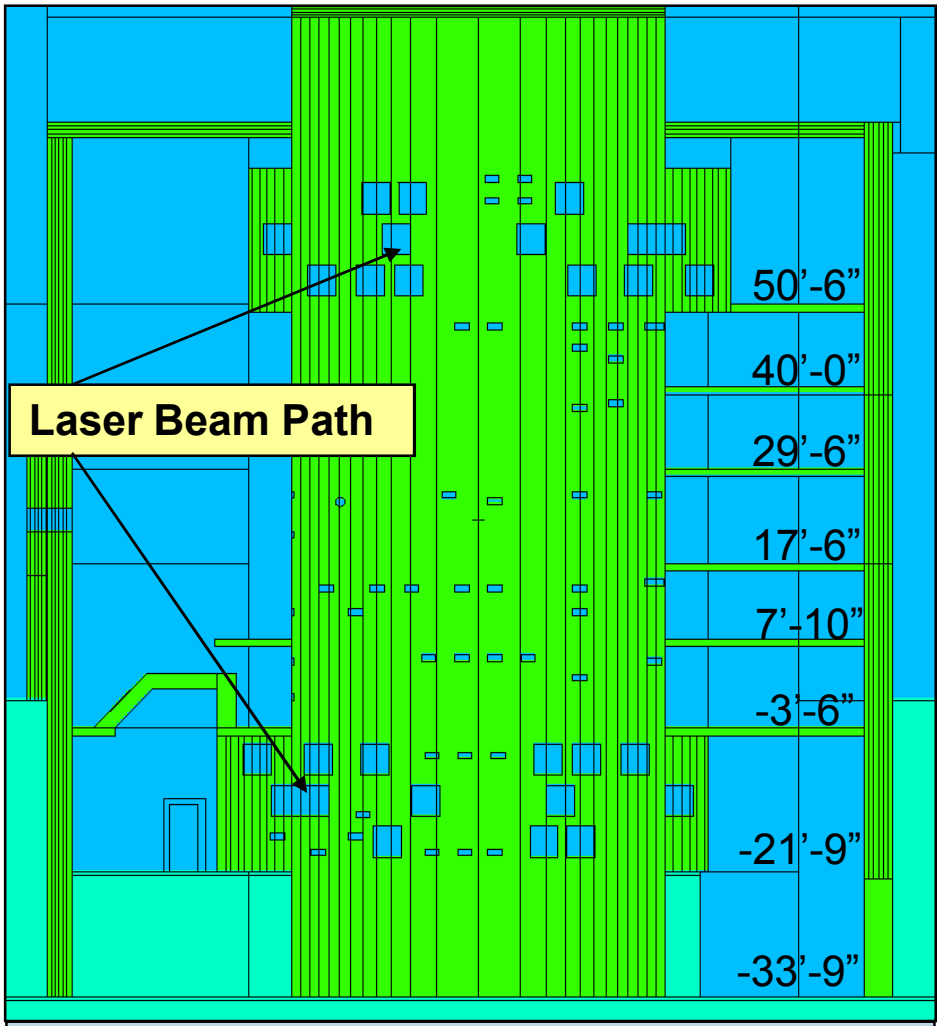
Radiation pathways

- Target Chamber penetrations
  - 48 indirect-drive beam ports (FOAs)
  - 24 direct-drive beam ports
  - 120 diagnostic ports
- Target Bay wall penetrations
  - Laser beam path in TB walls
  - 175 utility penetrations (38% shielded)
  - 10 diagnostic penetrations
- West Switchyard wall penetrations
  - 18 utility penetrations
  - 2 diagnostic penetrations
- East Switchyard wall penetrations
  - 26 utility penetrations
  - Laser beam tubes at the 17’ 6” level
- Doors
  - Target Bay: 20 primary (19 shielded)
  - Switchyards: 32 secondary (27 shielded)

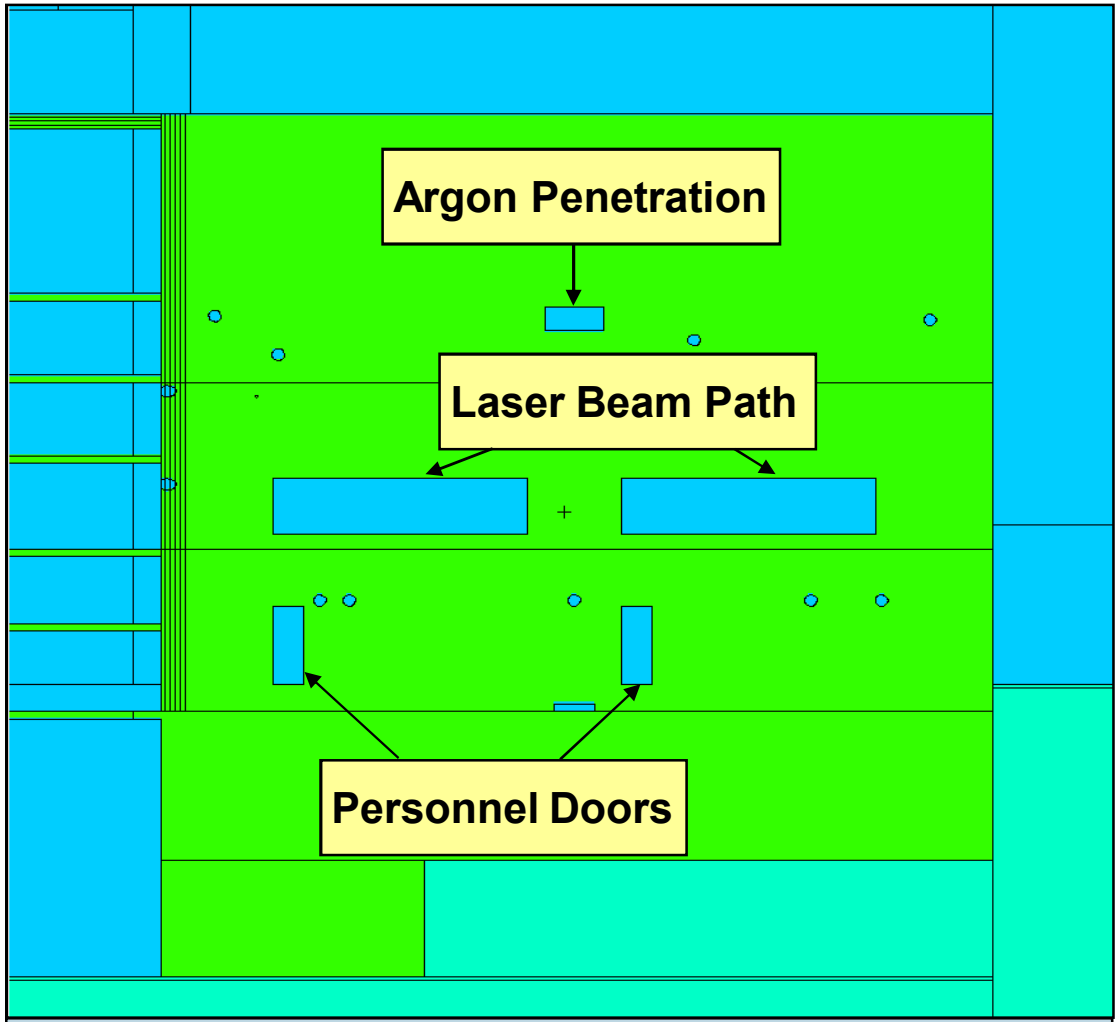
Horizontal view of TB at TCC



Vertical view of Q1 and Q4 of TB wall

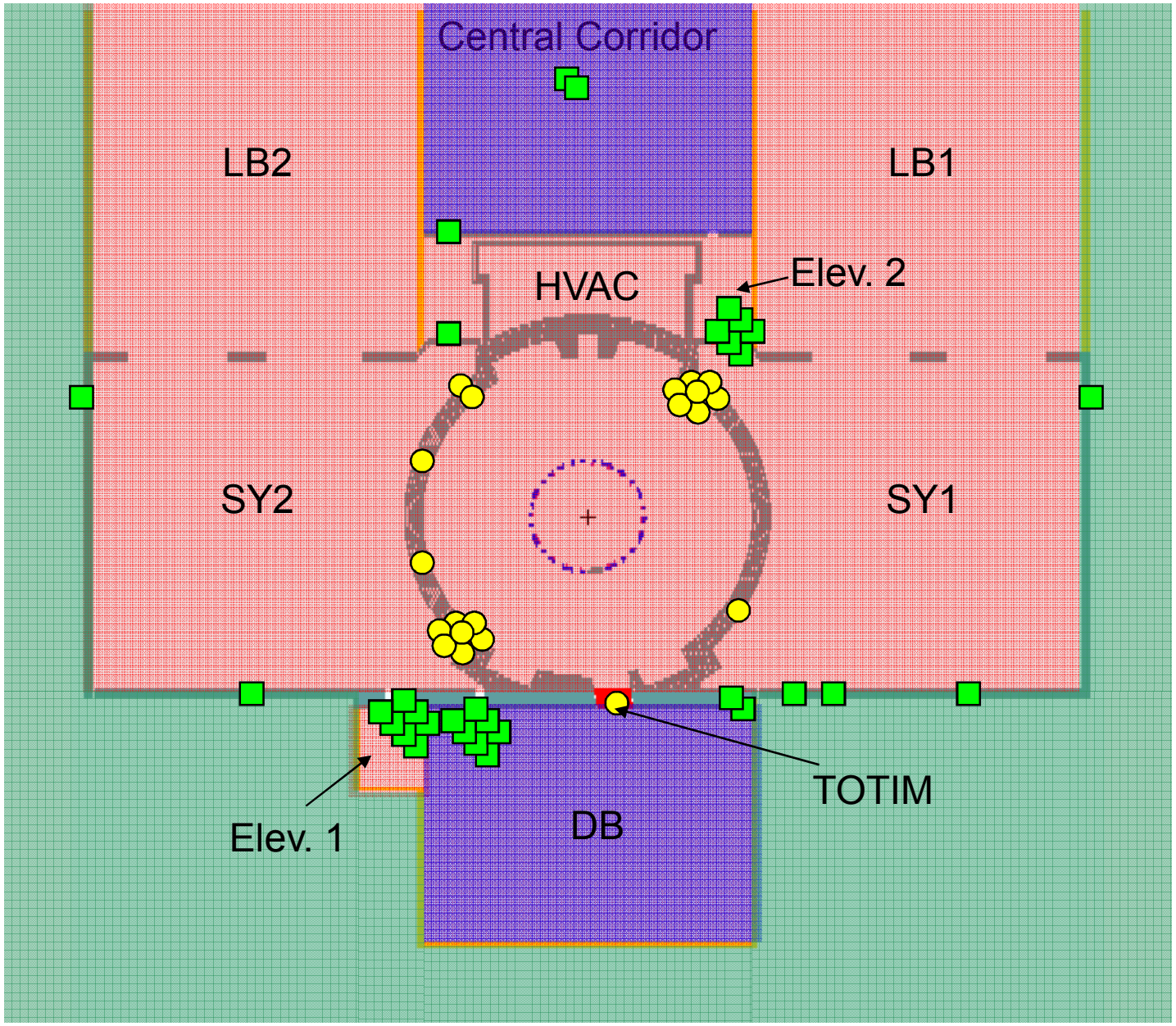


Vertical View of Q1 and Q4 of TB Wall



Vertical View of East Wall of SY1

Summary of shield door locations



- Exclusion areas
- Normally occupied areas within the facility
  → 1/3 occupancy
- Occasionally occupied areas outside the facility
  → 1/16 occupancy

- Primary shield door
- Secondary shield door

Thicknesses of the primary and secondary shield doors were optimized

Radiation environment during different phases of the NIF operation

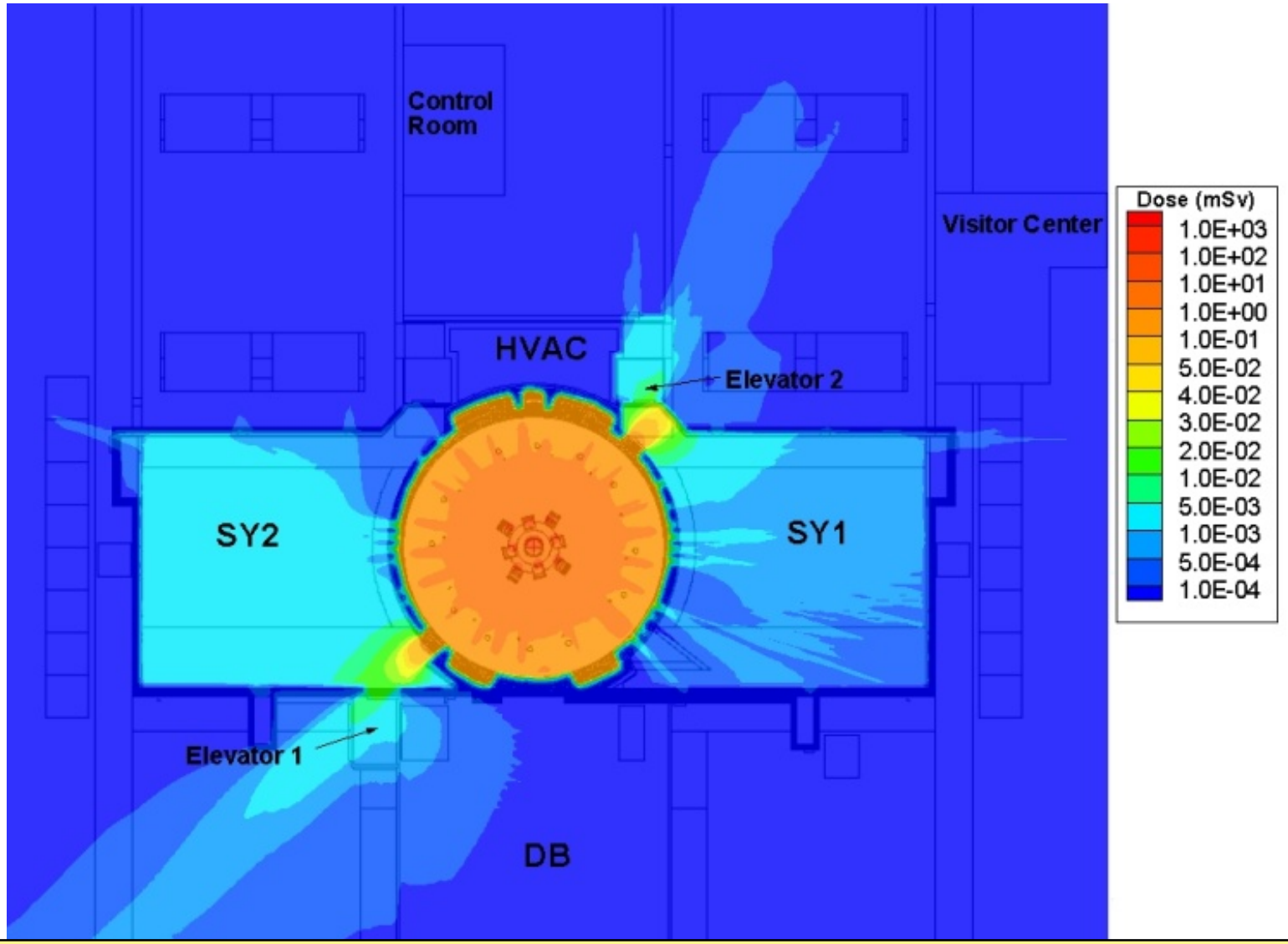
- Phase I: X-rays due to 3 ω laser interaction with target (up to 1.8 MJ of laser energy)
- Phase II: 2.45 MeV neutrons during D-D shots (up to 12 J or 10^{13} neutrons per shot and ≤ $2x10^{15}$ neutrons per year)
- Phase III: 14.1 MeV neutrons during THD or D-T shots (up to 10^{16} neutrons per shot and ≤ 10^{19} neutrons per year)
- Phase IV: 14.1 MeV neutrons during D-T shots (up to 20 MJ or $7.1x10^{18}$ neutrons per shot and ≤ 1200 MJ or $4.2x10^{20}$ neutrons per year)

Results for low yield D-T shots (Phase III) are presented in this talk

Simulation approach/assumptions

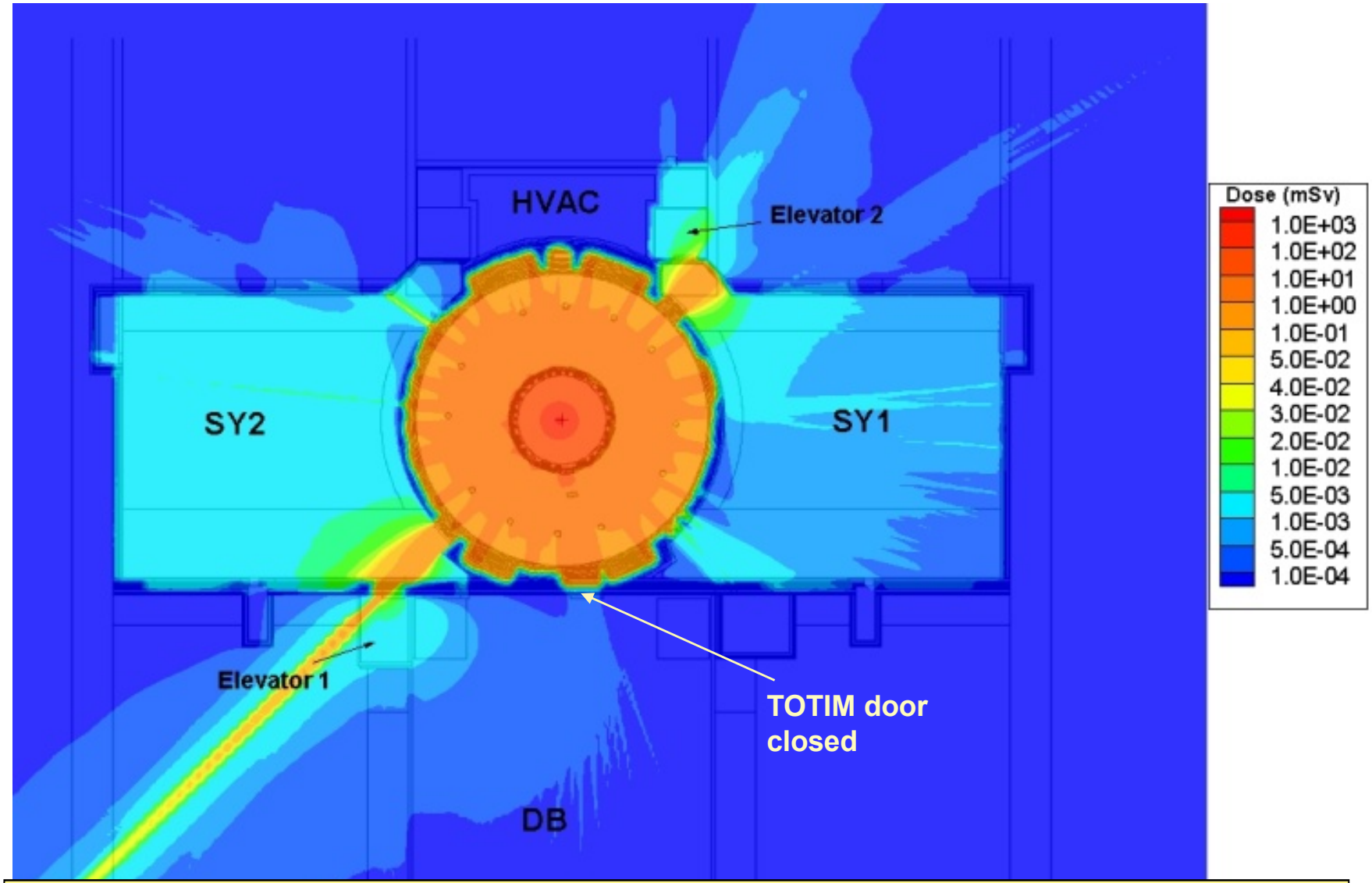
- Radiation transport simulations performed using the MCNP code
- Particle splitting and Russian roulette are used throughout the geometry
- Particle tracks are followed using tally cell-flagging cards
- Mesh tallies are used to produce prompt dose maps of the entire facility
- ICRP-74 fluence to effective dose conversion factors
- Analyses are presented for the following categories of low yield D-T shots:
  - Category A – < 10^{14} neutrons per shot
  - Category B - > 10^{14} and < 10^{16} neutrons per shot
- Only TOTIM is closed during Category A shots and all other primary shield doors are closed during Category B shots
- The NIF radiological design goal is to limit the maximum prompt dose in any occupied area to < 50 μSv per shot and < 1 mSv per year

Prompt dose map of the ground floor level during a Category A shot



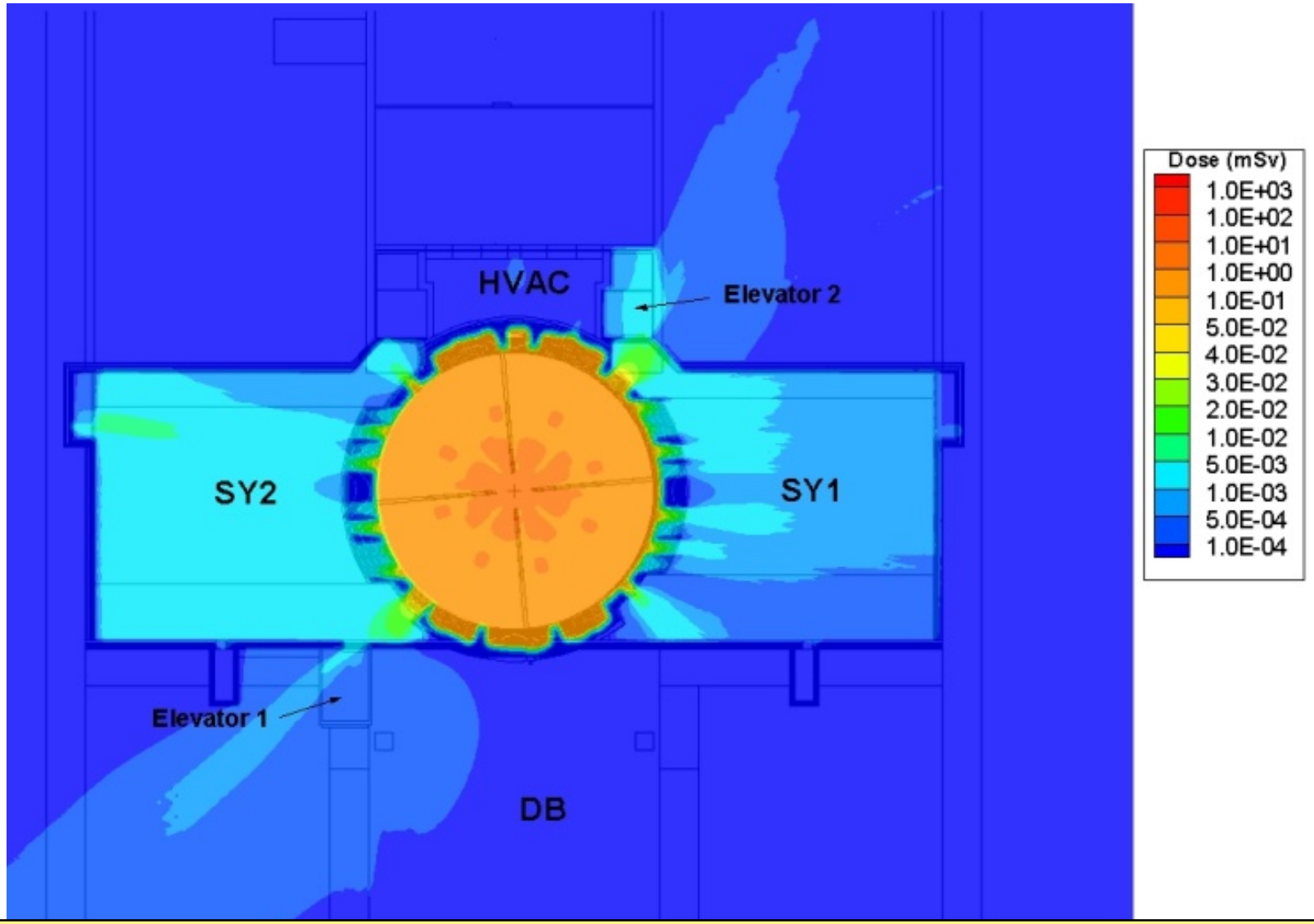
Dose in a near-by building at ~ 100 m from TC center is only 0.003 μSv and the dose at the nearest site boundary (at 350 m from TCC) is ~ 2.5×10^{-4} μSv per shot

Prompt dose map of the 17’ 6” floor level during a Category A shot



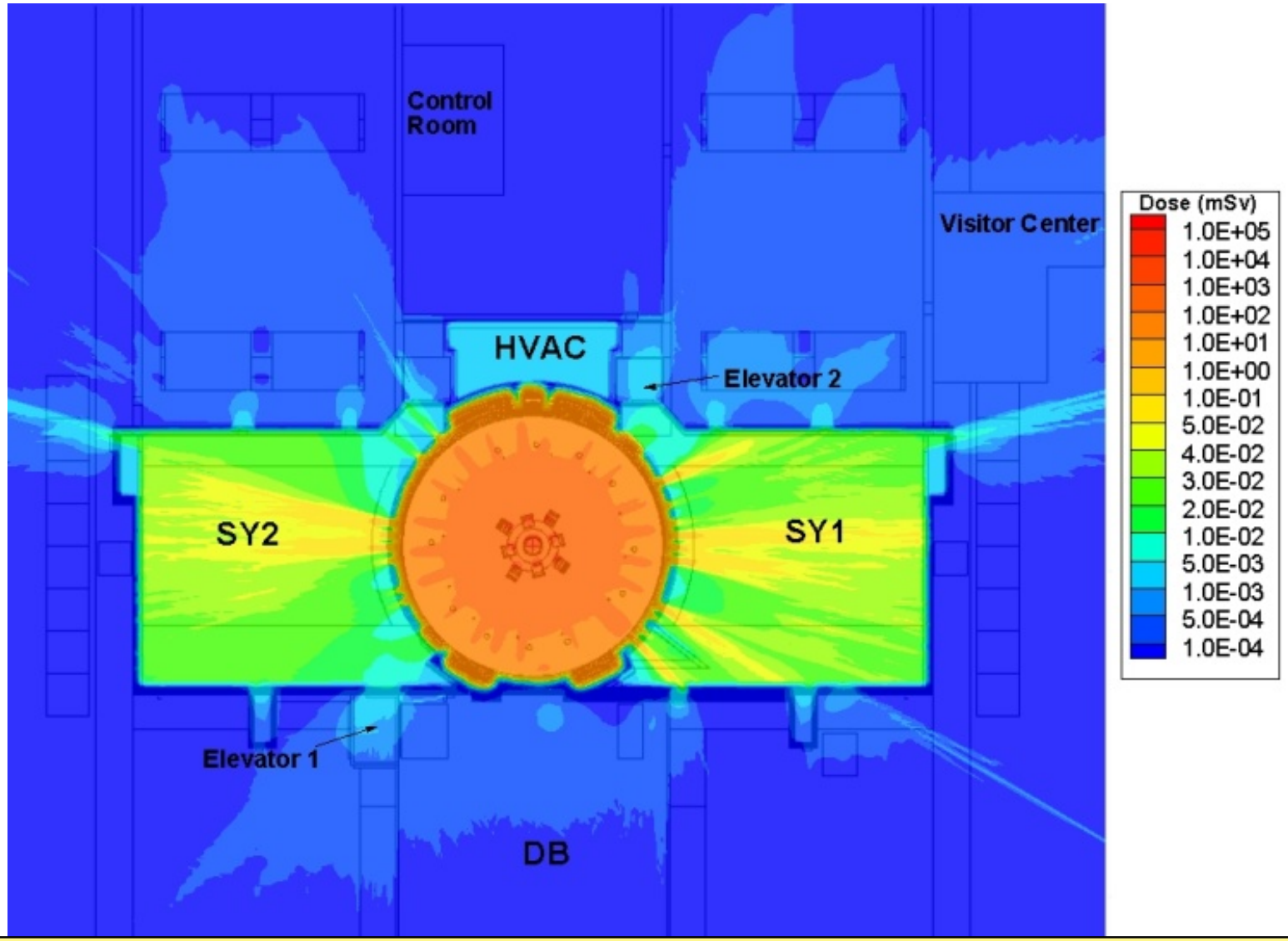
Dose values range from a maximum of 12 mSv inside the unoccupied TB to < 2 μSv in the occupied DB

Prompt dose map of the 50’ 6“ floor level during a Category A shot



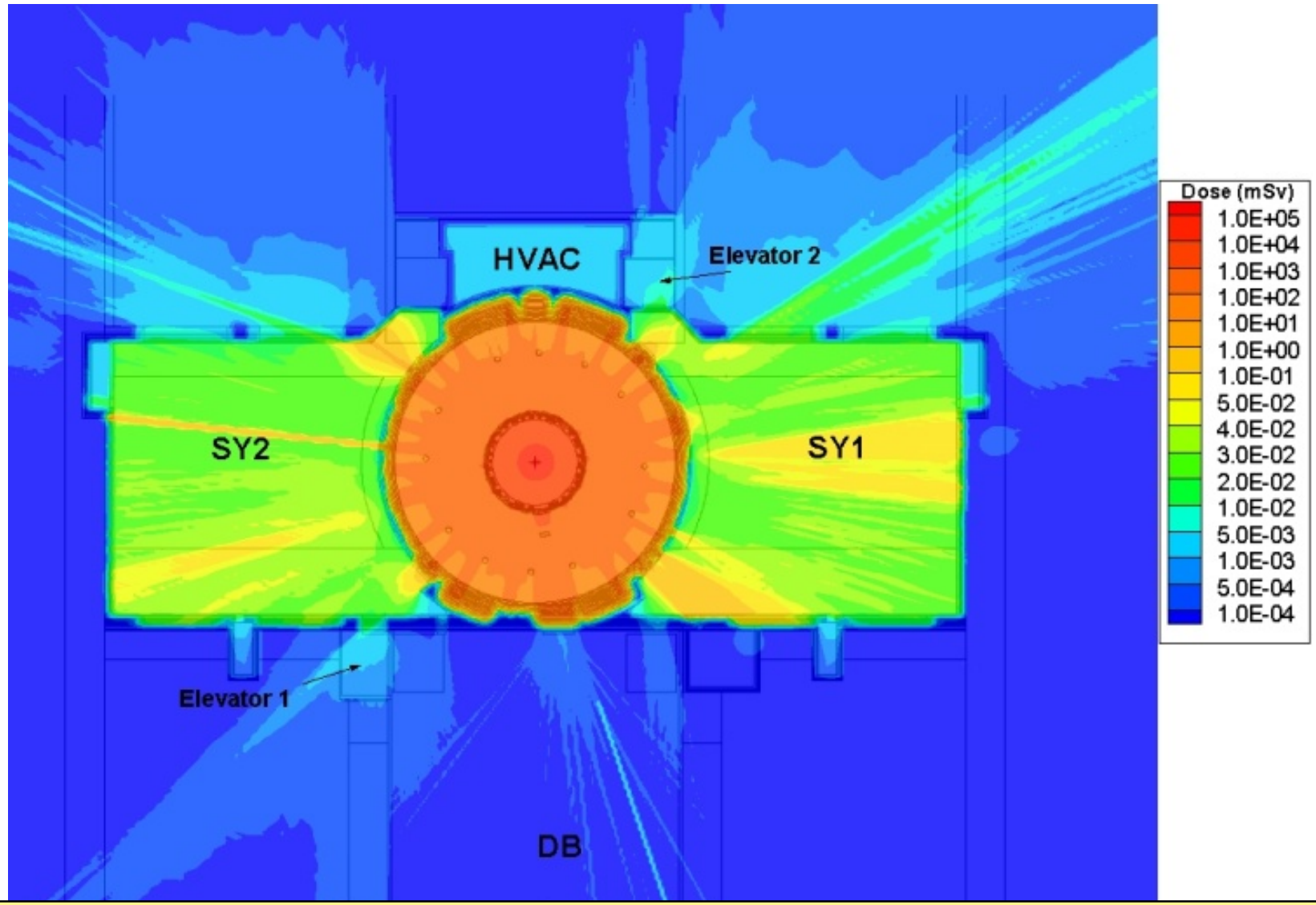
TB wall thickness has been increased from the nominal 1.83 m to 3.66 m around beam tube penetrations

Prompt dose map of the ground floor level during a Category B shot



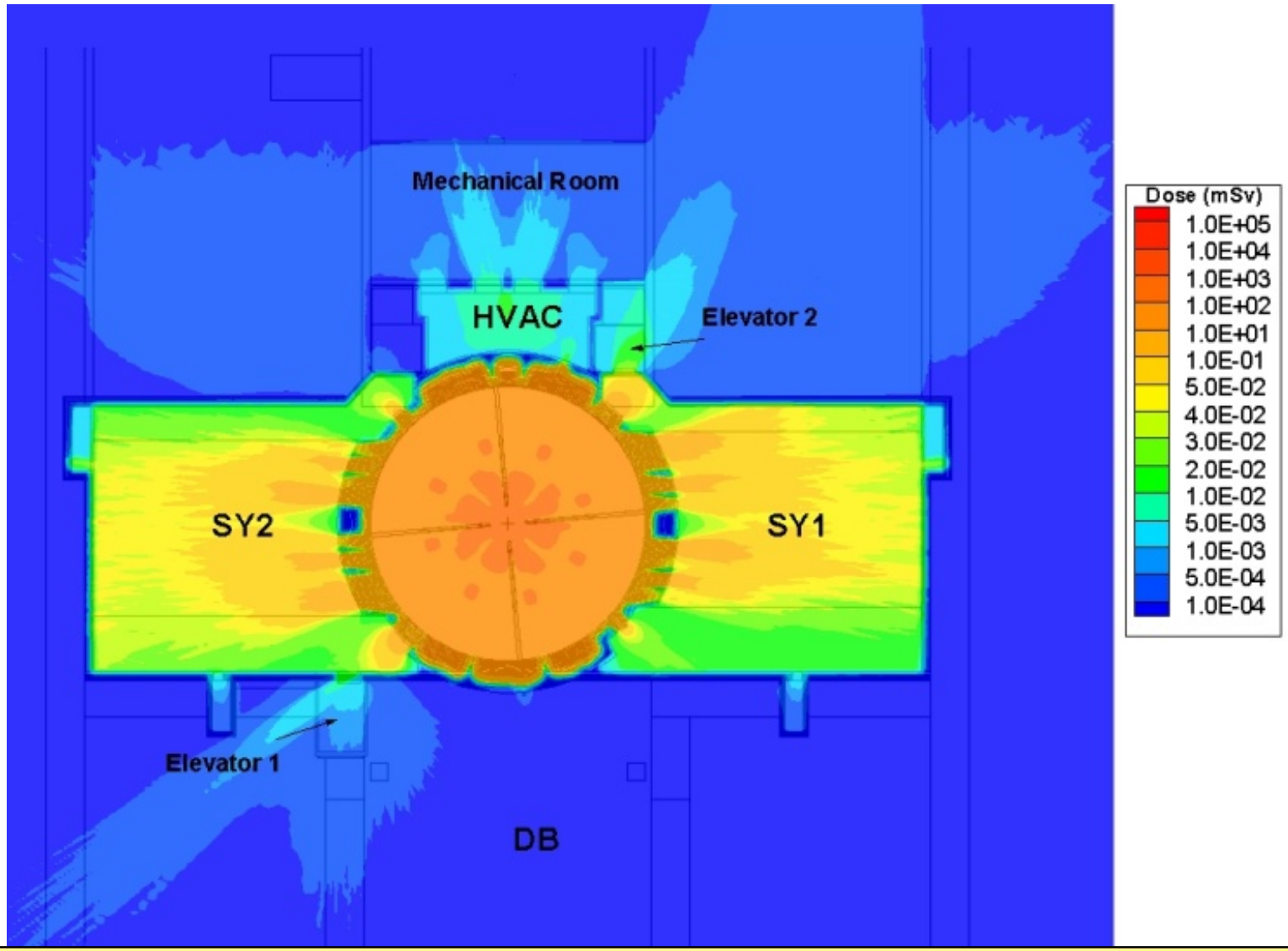
Dose in other occupied areas like the control room and visitor center are 0.02 μSv and 0.2 μSv per shot, respectively

Prompt dose map of the 17’ 6” floor level during a Category B shot



Closing of primary shield doors helps in reducing the maximum dose in the SYs to ~ 0.5 mSv, and the dose in the occupied DB remains at ~1 μSv per shot

Prompt dose map of the 50’ 6“ floor level during a Category B shot



Radiation streaming from the HVAC into the MERs thru the air handler penetrations does not result in any significant dose in occupied areas outside the rooms

Maximum estimated prompt dose values (μSv)

Location	Floor level	Category A Shot	Category B Shot
Diagnostics Building	-33' 9"	0.45	0.32
Diagnostics Building	-21' 9"	1.5	0.83
Diagnostics Building	-3' 6"	1	0.6
Outside SY1	Ground	0.22	7.3
Outside SY2	Ground	0.24	7.5
Control Room	Ground	0.003	0.02
Visitor Center	Ground	0.013	0.2
Diagnostics Building	7' 10"	1.5	3.2
Diagnostics Building	17' 6"	2	1
Diagnostics Building	29' 6"	1.5	0.5
Diagnostics Building	40' 0"	1.7	3.2

Dose values in occupied areas are well below the 50 μSv NIF design goal limit

Summary

- Detailed analyses of expected prompt dose values during Phase III of the NIF operation (low yield D-T shots) have been completed
- Targets with maximum neutron yield of 10^{14} and 10^{16} neutrons will be used during Category A and B shots, respectively
- No shield doors other than the TOTIM door are required to be closed for Category A shots
- All Target Bay primary shield doors are closed during Category B shots
- No secondary shield doors are required for any of the shots
- The maximum dose values inside potentially occupied areas are small, estimated at 2 and 7.5 μSv per shot during the Category A and B shots, respectively
- Maximum dose values in a near-by building and at the nearest site boundary are 0.03 and 0.01 μSv per shot, respectively
- Dose values inside and outside the NIF during low yield D-T shots are small and do not pose a hazard to workers, visitors or the public


NIF
National Ignition Facility